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Land use implications of future energy system trajectories—The case of the UK 2050 Carbon Plan

D. Dennis Konadu[a,*], Zenaida Sobral Mourão[a], Julian M. Allwood[a], Keith S. Richards[b], Grant Kopec[a], Richard McMahon[a], Richard Fenner[a]

[a] Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, United Kingdom
[b] Department of Geography, University of Cambridge, Downing Place, Cambridge CB2 3EN, United Kingdom

HIGHLIGHTS

- The Carbon Plan could result in significant land use change for bioenergy by 2050.
- Higher Nuclear; less efficiency pathway has the highest land use change impact.
- Higher Renewables; more energy efficiency pathway has the lowest land use change impact.
- Transport decarbonisation via biofuels has the highest land use change impacts.
- At current deployment rate only Higher Renewables pathway projections is achievable.

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ABSTRACT

The UK's 2008 Climate Change Act sets a legally binding target for reducing territorial greenhouse gas emissions by 80% by 2050, relative to 1990 levels. Four pathways to achieve this target have been developed by the Department of Energy and Climate Change, with all pathways requiring increased us of bioenergy. A significant amount of this could be indigenously sourced from crops, but will increased domestic production of energy crops conflict with other agricultural priorities?

To address this question, a coupled analysis of the UK energy system and land use has been developed. The two systems are connected by the production of bioenergy, and are projected forwards in time under the energy pathways, accounting for various constraints on land use for agriculture and ecosystem services.

The results show different combinations of crop yield and compositions for the pathways lead to the appropriation of between 7% and 61% of UK's agricultural land for bioenergy production. This could result in competition for land for food production and other land uses, as well as indirect land use change in other countries due to an increase in bioenergy imports. Consequently, the potential role of bioenergy in achieving UK emissions reduction targets may face significant deployment challenges.

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1. Introduction

The deployment of low-carbon/renewable energy, in particular bioenergy, as substitutes for fossil fuel in transport and heat delivery has been shown to have the potential of playing a significant role in the future UK energy systems (Jablonski et al., 2010). The UK Department of Energy and Climate Change (DECC) in its pursuit of ensuring a low-carbon energy future, has developed the 2050 Carbon Plan (HM Government, 2011). The Carbon Plan is made up of four low-carbon energy system pathways that achieve the 80% greenhouse gas (GHG) emissions cut target of the Climate Change Act (2008) (HM Government, 2008) by 2050. These are: “Core MARKAL”; “Higher Renewables, more energy efficiency”; “Higher Nuclear, less energy efficiency”; and “Higher Carbon Capture and Storage (CCS), more bioenergy”. The energy and technology mix of all these pathways have a significant composition of renewables. With the exception of hydro, tidal and offshore wind power generation, the majority of renewable energy systems involve some form of land use – bioenergy being the most land intensive. Thus, a fundamental question for policy is whether these pathways could have a significant impact on land use, and if so, could this create competition between energy, food and other land services for available suitable UK land? Answering this

* Corresponding author. Tel.: +41223332875.
E-mail address: ddk24@cam.ac.uk (D.D. Konadu).

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question requires a comprehensive analysis of the land required under each of the pathways and for other land services, vis-à-vis the available UK land. This is the main objective of the current study.

The Carbon Plan assumes that a range of bioenergy sources can assist with the achievement of the bioenergy projections for each of its pathways, including bioenergy from crops, dedicated and waste wood fuel, agricultural residue, and biomass waste in landfill. These provide the raw materials for the generation of electricity, heat and liquid biofuels. Potential land use impact in this context would therefore be mainly associated with the production of energy crops. Currently, bioenergy feedstock for heat and electricity generation is mainly from imported solid biomass, with a limited supply of wastes and straw sourced indigenously (AEA, 2014). Additionally, 85% of crop-based feedstock for biofuels for road transport for 2013/14 in the UK was imported (DEFRA, 2014a, 2014b). While the Carbon Plan envisages the importation of a greater portion of UK bioenergy feedstock to continue in the future, there is scope for a significant amount to be indigenously sourced, including bioenergy from energy crops. It is therefore important to assess requirements for land to produce the anticipated increase in indigenous bioenergy, and to explore whether restrictions on land availability could prevent realisation of future energy system targets.

According to the UK's Department for Environment, Food and Rural Affairs (DEFRA), 51,000 ha (0.8%) of UK arable land was used for the production of bioenergy in the UK in 2014 (DEFRA, 2014a, 2014b). Out of this land area, 42,000 ha was for the production of first-generation energy crops (including wheat, oil seed rape, and sugar beets) used in the production of liquid transport biofuels (biodiesel and bioethanol). The remainder (9000 ha) was used in the production of second-generation energy crops, mainly short rotation coppice (SRC) and Miscanthus, which is used for heat and electricity generation. This level of land appropriation for bioenergy production threaten other uses. However, future changes in the UK energy system, could according to Popp et al. (2014), result in significant changes to the current UK agricultural landscape and management practices. This might include sustainable intensification that improves yields, with increased fertilizer application, and replacement of certain crops (e.g. Franks, 2014; Fish et al., 2014), or by exploitation of unused arable land, as well as use of other productive and marginal lands (e.g. Horrocks et al., 2014). This increased indigenous feedstock production could lead to some level of future land stress in the UK. Additionally analysis by Smith et al. (2010) of UK land use and food production suggests that with future increases in population and food demand, increased competition for suitable land for bioenergy supply, food production and other land services could arise. Moreover, the EU Renewable Energy Directive, sets out binding sustainability criteria for sourcing bioenergy, stipulating that feedstock are sourced without loss of high carbon lands including forests, peat and bog, that biodiversity is maintained, and that protected areas including conservation, national parks and primary vegetation cover are preserved (EU, 2009).

Currently, there are no specific policy targets for UK-sourced crop-based bioenergy, and by extension there are no targets for areas of land that would be required. However, several government publications have estimates land requirements. According to the UK Bioenergy strategy (DECC, 2012a, 2012b) between 300,000 ha and 900,000 ha of UK agricultural land could be required by 2030. Analysis in the 2011 Bioenergy Review of the Committee on Climate Change (CCC) envisages that between 300,000 ha and 800,000 ha would be required by 2050 to deliver between 15 TW h and 70 TW h energy (CCC, 2011). Prior to these reports, DEFRA's 2007 UK Biomass Strategy also projected that up to 350,000 ha and 800,000 ha would be required by 2020 and 2050 respectively. Studies on the availability of land for bioenergy production in the UK have a range of outcomes, particularly for second-generation energy crops, which are projected to be the main future bioenergy feedstock (HM Government, 2011). Considering various limiting factors, including physical limits to production (topography, drainage etc.), biodiversity conservation, socio-cultural services, existing land use, and a variety of landscape designations and aesthetics, Lovett et al. (2014) estimated that about 8.5 Mha ~37% of the UK's agricultural land, is potentially suitable for perennial bioenergy production. According to a report by Ricardo-AEA (2014) for DEFRA, this potential suitable land decreases to 6.4 Mha if Agricultural Land Class (ALC) Grades 1 and 2 land were excluded, and decreases further to 1.4 Mha if ALC Grade 3 land was also excluded. There is however, a wide range of estimates of available land that could be converted to bioenergy production due to differences in the assumptions used. According to Welfle et al. (2014), if food security, economic development, conservation, and bioenergy were prioritised for land use to 2050, between 0.7 and 2.2 Mha could be available. Aylott and McDermott (2012) also concluded that between 0.93 and 3.63 Mha of land for Miscanthus and SRC production in the UK could be available. However, if a gross margin of £526/ha for Miscanthus (at £60/odt) is assumed to be the minimum acceptable to farmers, the maximum available area reduces to 0.72–2.80 Mha. Similarly, at a gross minimum margin of £241/ha for SRC (at £60/odt) the land availability decreases to 0.62–2.43 Mha (Aylott and McDermott, 2012).

Other studies have also looked at the wider ecosystem and biodiversity impacts of large-scale bioenergy deployment in the UK. The studies have shown that second-generation energy crops (such SRC and Miscanthus), will probably have positive effects on soil properties, biodiversity, energy balance, greenhouse gas (GHG) mitigation, carbon footprint and visual impact when compared to arable crops (e.g. Rowe et al., 2009; Thornley et al., 2009; Rowe et al., 2013; Milner et al., in press; Holland et al., 2015). However, the positive effects depend mainly on previous land uses rather than the choice of the second-generation crop, with a transition from arable crops to bioenergy being best (Milner et al., in press). Additionally, if not managed carefully, bioenergy production could pose a significant challenge to maintaining biodiversity and the ecosystem services currently provided by land (Rowe et al., 2009)

Whilst most of these analyses are predicated on UK and/or EU policy, none have directly analysed the land implications of the energy pathways in the Carbon Plan. This study therefore aims to analyse the land use requirements of the four Carbon Plan pathways from 2010 to 2050 under different scenarios of yield and energy crop composition and considers the implication of these pathways on other land services including food production, settlement expansion and biodiversity protection.

2. Methodology

To determine how the UK Carbon Plan pathways could lead to competition for agricultural land, this study uses a top-down analysis of the interconnections between the land and energy systems, followed by the estimation of the area of land required to deliver the bioenergy component the pathways, and how this affects UK land use distribution. First, linkages between the energy and land systems were mapped out and the current land area appropriated for energy crops was analysed. Next, the land area requirements for the projected bioenergy component of each pathway, and for other services were estimated. Then the, land use distribution under each pathway was analysed using criteria that prioritise food production and the maintenance of ecosystem services to establish potential land stress and competition

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